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Energy saving on tramline in Craiova

CiViTAS
Cleaner and better transport in cities

MODERN
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Definition of methodology and measure concept

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1. MODERNIZATION OF ELECTRICAL PUBLIC TRANSPORT

In the last few years the number of vehicles is continuously growing due to the living standard, necessity to improve mobility and, also, because the costs for achieving and maintain a vehicle is decreasing.

This growth is the main cause of traffic flow increasing, especially in medium and large cities. A more and more difficult transport with private cars, increased level of pollution and insufficient parking places lead to the necessity of a more efficient public transport.

Especially the public transport with vehicles which are not polluting (trams, elevate subways and subways) is improved.

In many advanced European countries huge funds are allocated to promote the use of the public transport system. The main arguments for this promotion are: environment protection, safety for pedestrians, traffic optimization. Regarding environment protection, a very increased attention is paid to the use of non-polluting vehicles. In many western European cities public transport with trams is improved in urban and suburban areas. In some cities from France (Lille, Monpellier, Nantes, Orleans, Strasbourg) the entire infrastructure for tram transport is fulfilled, in other cities (Grenoble, Paris, Rouen, Saint-Etienne) the tram based was renewed. In Germany(Berlin, Bochum, Bonn, Bremen, Darmstadt, Dortmund, Dresda, Frankfurt, Hanovra, Heidelberg, Jena, Karlsruhe, Kassel, Koln, Lepzig, Ludwigshafen, Magdeburg, Mainz, Mannheim, Munchen, Nurnberg, Obershausen, Postdam, Rostock, Wurzburg) in which the public transport with trams had an increased development in `70, the trends are to renew the base of tram and to modernize the infrastructure. Same trends are present in cities from Austria(Graz, Vienna), Belgium (Bruselles, Charleroi), Switzerland (Basel Bern, Geneva, Zurich), Finland, Italy, Great Britain, Holland, Portugal, Spain and Sweden; in the same time suburban and urban transport with elevate subways(LRV)is increased using the existent infrastructure for trams, a new infrastructure or regional railways.

In central and eastern euorpean countries these trends are moderate, related to Western Europe, due the lack of funds. Still, there are sustained concerns in that way in Czech Republic (Brno, Liberec, and Prague), Croatia (Zagreb), Poland (Poznan, Warsaw), Slovakia (Bratislava) and Hungary (Debretin). Local transport companies in these cities manage to find funds for renewing trams base aiming to increase passengers comfort and to have a more efficient transport activity. In central and eastern euorpean countries , in order to satisfy the requests from public transport in short time and with a small budge, used trams (manufactured in `60-`70) were acquired. A long-term consequence of this achievement is that the exploitation costs are increased because of big and unjustified energy consumption.

Intelligent transport systems are very well known to have a major favourable impact on the reliability of the services in urban transport. In the entire world there are several logistic and tracking systems and some manufacturers produce vehicles with electronic navigation system on board. In some developed countries there are system that, beside traffic management provides additional functions like fare administration, electronic commerce, automatic transmission of related papers, etc.

In Romania, some institutions or private companies from industrial area and, also, research field, are in different stages of development of these intelligent systems.

These implementations are prior for public institution with a serious need for vehicle surveillance and management: police departments, fire stations, emergency services, intern and international transport of goods, etc. These systems are dedicated to the process, private and less wavering.

In the entire world, the main requirements in developing public transport with trams are:

- Increase commercial speed of the vehicle
- Improve the quality of services
- Reduce exploitation and maintenance costs

Different studies about increasing efficiency in public transport, taking into account these requirements and the actual economical context, shows that the modernization of the existing trams is the optimal solution. Local transport operators are in subordination of local authorities and in the most cases it is impossible to finance their own research and development activities. They are limited to keep in use the actual vehicles and the high competition with private transport companies make them vulnerable regarding to citizen's interest especially when private companies work in areas with intensive traffic.

Because public transport with trams and trolleys is more economic it is necessary to increase his efficiency.

In order to optimize energy consumption and public transport costs the major objectives are:

- Making romanian public transport compatible with european public transports, regarding energy consumption standards and adapts the consumption to passenger flow.
- Increasing passenger comfort;
- Reducing maintenance and exploitation costs with modern electrical driving solutions;
- Automatization of the personnel activity in maintenance and exploitation;
- Modern solution which allow that the infrastructure to be functional compatible with european system;
- Modern technologies for transport services according to international requirements and european standards;

A significant part of these objectives is reached by the implementation of a chopper system for electrical drive motors on trams, in order to obtain a reduce energy consumption.

An additionally measure is to make the compatibility between the main parts of the equipments related to public transport network and the actual electrical network. For example: design static power supply sources for auxiliary services and make them an integrated part of the chopper.

Also, modern techniques are required, for measuring a surveillance using dedicated software and for the implementation of a unique structure to watch, control, and drive all tram's devices (board computer).

The complexity of this structure is indisputable. From all the equipments of the structure the more important, due to its advantages, is the chopper.

The main functions of the chopper are:

- Optimal supply for electrical drive motors;
- Supervises and limits the motor current to prescribed values; increase de life-cycle of the motor;
- Reduces with 70% the number of power contacts and controls their coupling and decoupling(avoids the breaking of the load current);
- Reduces shocks for start and braking regimes; increase safety in public transport; reduces mechanical stress leading to increased life-cycle;
- Supervises, display and stores permanently all the input and output signals for future fault tracings;
- Numerical data processing in order to supervise some energetic parameters and some performance indexes;
- Locates and detects faults;
- Stores normal and fault electrical events leading to efficient energy consumption and improved maintenance activity;
- Signals the exceeding of limits for some electrical parameters.

2. GENERAL STRUCTURE OF A MODERN SUPPLY SYSTEM FOR ELECTRICAL DRIVE MOTORS

As was specified before, it is an important number of trams that are very old (`60-`70) have continuous current motors. The ideal solution is to completely change de driving system with asynchronous (induction) motors. This is a very expensive taking into consideration the life cycle.

In conclusion, the optimal solution is the chopper system.

Choppers are DC-DC converters that are used for transferring electrical energy from a DC source into another DC source, which may be a passive load. These converters are widely used in regulated switching power supplies and DC motor drive applications.

DC-DC converters that are discussed in this section are one-quadrant, two-quadrant, and four-quadrant choppers. Step-down (buck) converter and step-up (boost) converters are basic one-quadrant converter topologies. The two-quadrant chopper, which, in fact, is a current reversible converter, is the combination of the two basic topologies. The full-bridge converter is derived from the step-down converter.

2.1 One-Quadrant Choppers

In one-quadrant choppers, the average DC output voltage is usually kept at a desired level, as there are fluctuations in input voltage and output load. These choppers operate only in first quadrant of *v*-*i* plane.

In fact, output and input voltages and currents are always positive. Therefore, these converters are called one-quadrant choppers.

One method of controlling the output voltage employs switching at a constant frequency, i.e., a constant switching time period ($T=t_{on}+t_{off}$), and adjusting the on-duration of the switch to control the average output voltage. In this method, which is called pulse-width modulation (PWM), the switch duty ratio *d* is defined as the ratio of the on-duration to the switching time period.

$$d = \frac{t_{on}}{T}.$$

In the other control method, both the switching frequency and the on-duration of the switch are varied. This method is mainly used in converters with force-commutated thyristors.

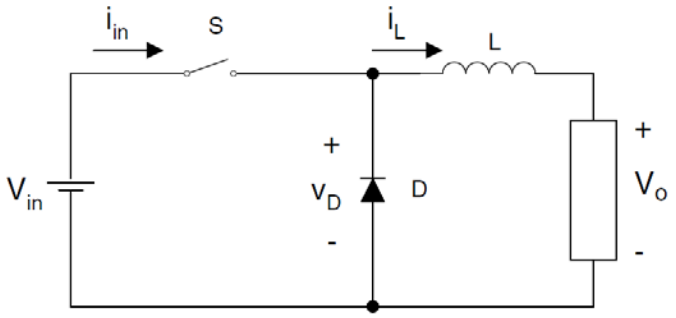

Fig. 1 Step-down buck converter

Choppers can have two distinct modes of operation, which have significantly different characteristics: continuous-conduction and discontinuous-conduction modes. In practice, a converter may operate in both modes. Therefore, converter control should be designed for both modes of operation.

Step-Down (Buck) Converter

A step-down converter produces an average output voltage, which is lower than the DC input voltage V_{in}. The basic circuit of a step-down converter is shown in Fig. 1.

In continuous-conduction mode of operation, assuming an ideal switch, when the switch is on for the time duration t_{on}, the inductor current passes through the switch, and the diode becomes reversebiased.

This results in a positive voltage ($V_{in} - V_o$) across the inductor, which, in turn, causes a linear increase in the inductor current i_L. When the switch is turned off, because of the inductive energy storage, i_L continues to flow. This current flows through the diode and decreases. Average output voltage can be calculated in terms of the switch duty ratio as:

$$v_{o,\,\text{ave.}} = \frac{1}{T}\int_0^T v_o(t)\,dt = \frac{1}{T}\left(\int_0^{t_{on}} V_{in}\,dt + \int_{t_{on}}^{T} 0.0\right) = \frac{t_{on}}{T}V_{in} = dV_{in} \qquad (1)$$

$v_{o,ave}$ can be controlled by varying the duty ratio ($d=t_{on}/T$) of the switch. Another important observation is that the average output voltage varies linearly with the control voltage. However, in the discontinuous-conduction mode of operation, the linear relation between input and output voltages is not valid. Figure 2 shows ($v_{o,ave.}$ / $v_{i,ave.}$) - $i_{o,ave}$ characteristic of a step-down converter in continuous and discontinuous conduction modes of operation.

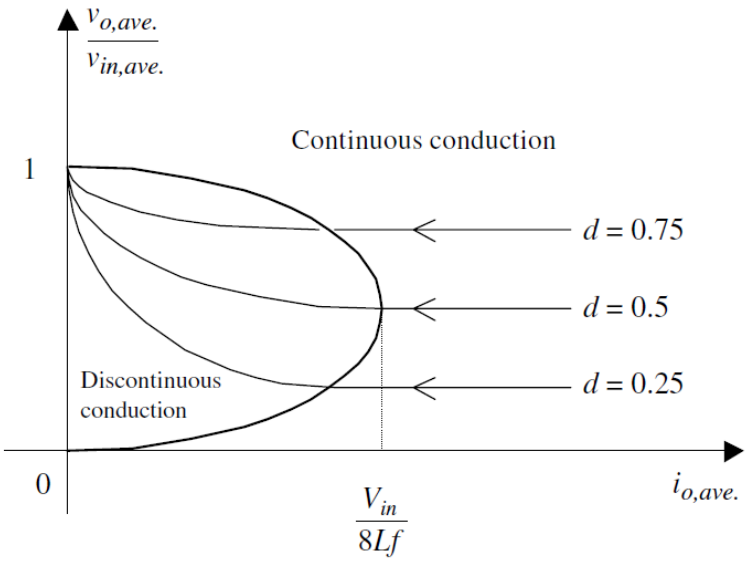

Fig. 2 ($v_{o,ave.}$ / $v_{i,ave.}$) - $i_{o,ave}$ *characteristic of a step-down converter*

Step-Up (Boost) Converter

Schematic diagram of a step-up boost converter is shown in Fig. 3. In this converter, the output voltage is always greater than the input voltage. When the switch is on, the diode is reversed-biased, thus isolating the output stage. The input voltage source supplies energy to the inductor. When the switch is off, the output stage receives energy from the inductor as well as the input source.

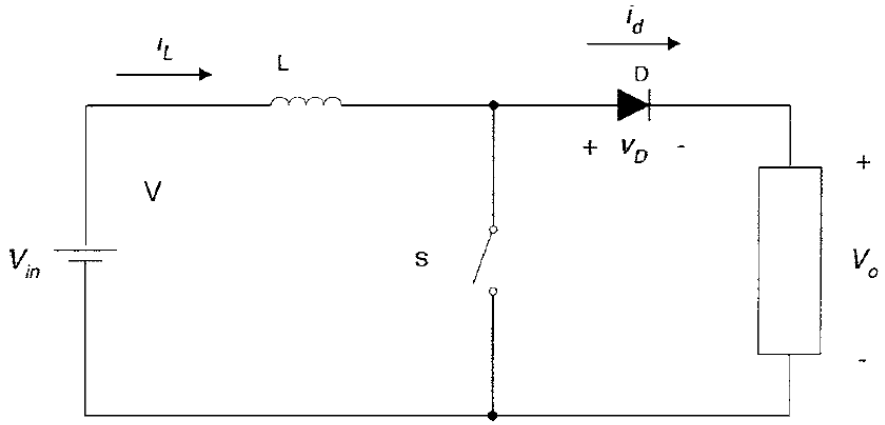

Fig. 3 Step-up boost converter

In the continuous-conduction mode of operation, considering *d* as the duty ratio, the input–output relation is as follows:

$$v_{o,\,\text{ave.}} = \frac{1}{1-d} V_{\text{in}} \tag{2}$$

If input voltage is not constant, *V*in is the average of the input voltage. In this case, relation (1) is an approximation. In the discontinuous-conduction mode of operation, relation (1) is not valid. Figure 4 shows ($v_{\text{o,ave.}}$ / $v_{\text{i,ave.}}$) - $i_{\text{o,ave}}$ characteristic of a step-up converter in the continuous- and discontinuousconduction modes of operation.

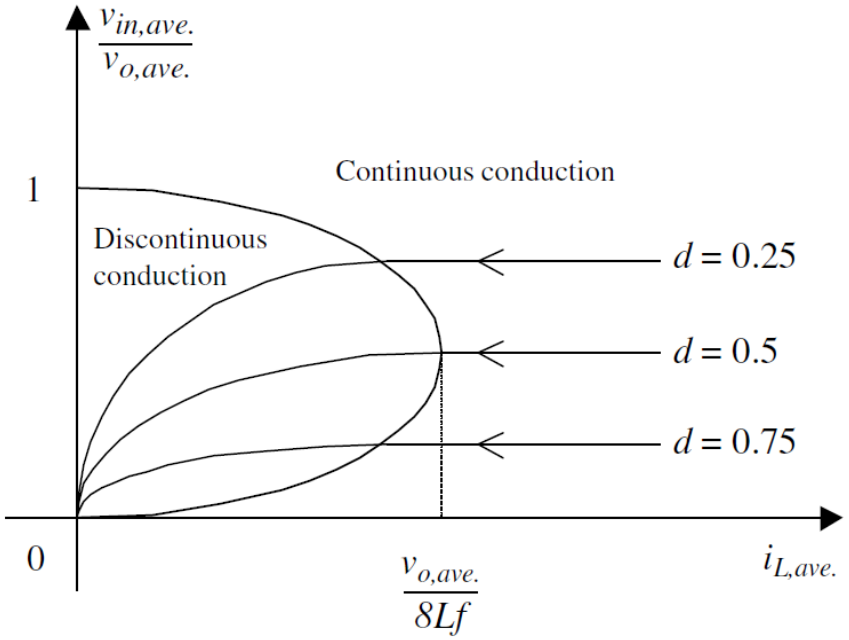

Fig. 4 ($v_{o,ave.}$ / $v_{i,ave.}$) - $i_{o,ave}$ characteristic of a step-down converter

2.2 Two-Quadrant Choppers

A two-quadrant chopper has the ability to operate in two quadrants of the (*v*–*i*) plane. Therefore, input and output voltages are positive; however, input and output currents can be positive or negative. Thus, these converters are also named current reversible choppers. They are composed of two basic chopper circuits. In fact, a two-quadrant DC-DC converter is achieved by a combination of two basic chopper circuits, a step-down chopper and a step-up chopper, as is shown in Fig. 5.

The step-down chopper is composed of S_1 and D_1, and electric energy is supplied to the load. The step-up chopper is composed of S_2 and D_2; electric energy is fed back to the source. Reversible current choppers can transfer from operating in the power mode to operating in the regenerative mode very smoothly and quickly by changing only the control signals for S_1 and S_2, without using any mechanical contacts.

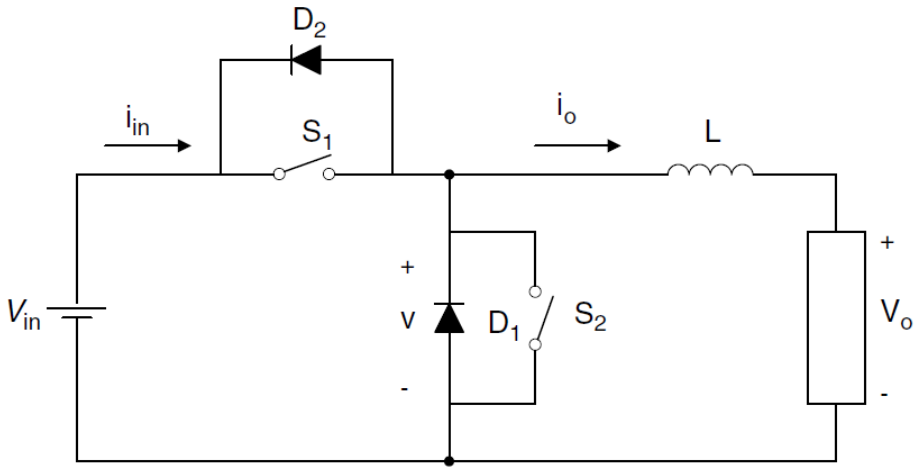

Fig. 5 A current reversible chopper

Figure 6 depicts the output current of a two-quadrant chopper. d_1 and $d_2 = 1 - d_1$ are the duty ratios of step-down and step-up converters, respectively. By changing d_1 and d_2, not only the amplitude of the average of the output current changes, but it can also be positive and negative, leading to two-quadrant operation.

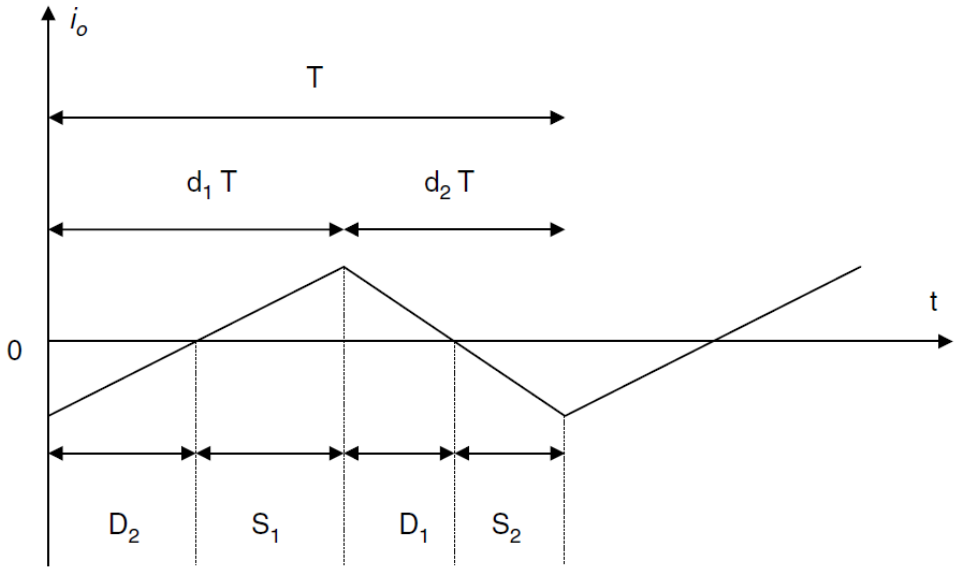

Fig. 6 Output current of a two-quadrant chopper

For each of step-down and step-up operating mode, relations (1) and (2) are applicable for continuous currents. However, in discontinuous-conduction modes of operation, relations (1) and (2) are not valid. Figure 7 shows the $(v_{o,ave.} / v_{i,ave.}) - i_{o,ave}$ characteristic of a two-quadrant converter in continuous- and discontinuous-conduction modes of operation. As is shown in Fig. 7, for changing the operating mode both from step-down to step-up operation and in the opposite direction, the operating mode must move from the discontinuous-current region. However, by

applying $d_2 = 1 - d_1$, the operating point will never move into the discontinuous-conduction region of the two basic converters. In Fig. 7, the broken lines indicate passage from step-down operation to step-up operation, and vice versa. In fact, because of this specific command - the relation between the two duty ratios – the converter operating point always stays in the continuous-conduction mode.

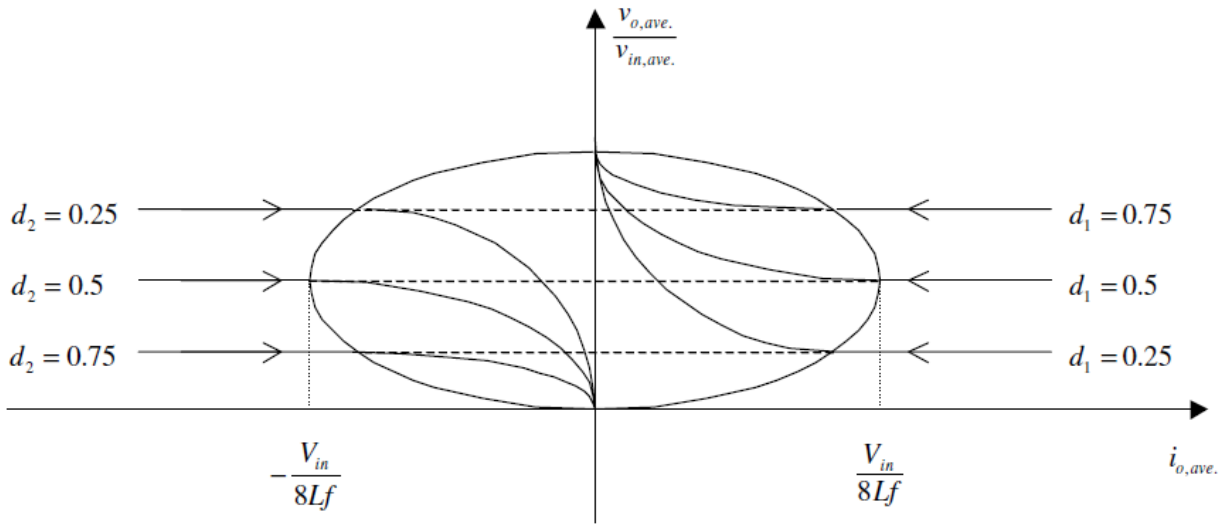

Fig. 7 ($v_{o,ave.}$ / $v_{i,ave.}$) - $i_{o,ave}$ characteristic of a two-quadrant converter

2.3 Four-Quadrant Choppers

In four-quadrant choppers, not only can the output current be positive and negative, but the output voltage also can be positive and negative. These choppers are full-bridge DC-DC converters, as is shown in Fig. 8. The main advantage of these converters is that the average of the output voltage can be controlled in magnitude as well as in polarity. A four-quadrant chopper is a combination of two twoquadrant choppers in order to achieve negative average output voltage and/or negative average output current.

The four-quadrant operation of the full-bridge DC-DC converter, as shown in Fig. 9, for the first two quadrants of the (v–i) plane is achieved by switching S_1 and S_2 and considering D_1 and D_2 like a two-quadrant chopper. For the other two quadrants of the (v–i) plane, the operation is achieved by switching S_3 and S_4 and considering D_3 and D_4 as another two-quadrant chopper, which is connected to the load in the opposite direction of the first two-quadrant chopper.

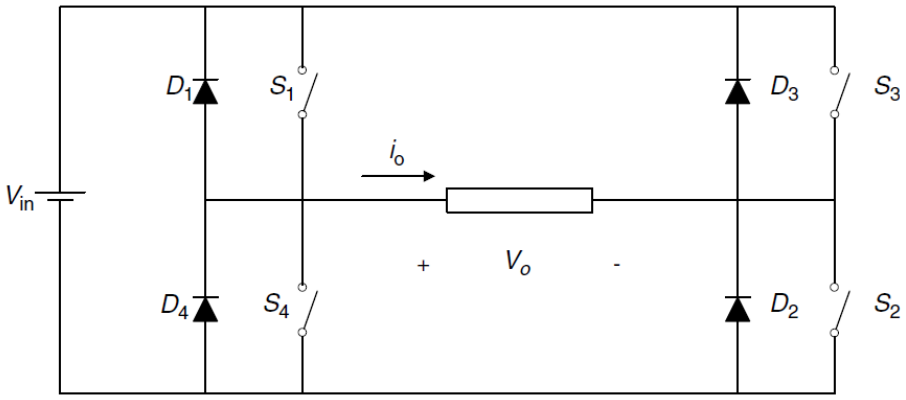

Fig. 8 A full-bridge four-quadrant chopper

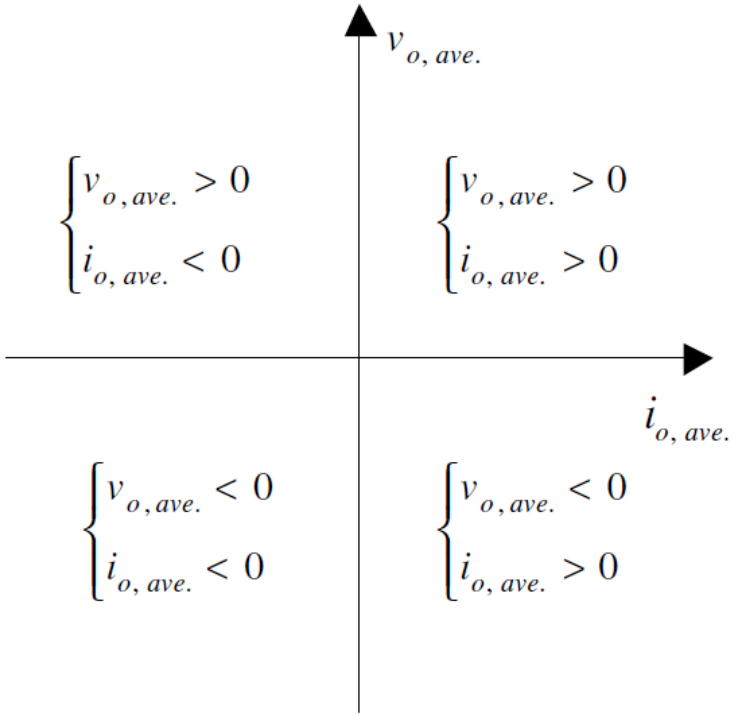

Fig. 9 Four-quadrant operation of a full-bridge chopper

3. CONCLUSIONS

Following the researches about modernization of electrical drive systems and according to actual legislation, and some solutions adopted by other transport operators, there are few characteristics for the choppers to follow. These characteristics were the basis of the tender book.

a. Chopper requirements

Being connected to the electrical scheme of the tram, the chopper has to ensure the proper supply for motors in start, braking and running regimes. For every regime the proper electrical diagram must be raised and the current motor must be controlled according to tram-driver's commands.
For electrical braking regime the system must decide if is electric brake switching or regenerative braking and the terminal voltage must not exceed the maximum admitted value.
The chopper must eliminate all electromechanical switching elements for the running-brake regimes.
The command unit of the chopper, current and voltage transducers and the afferent supply sources will be placed in chopper's enclosure.

The command unit will receive (mandatory CAN open communication) commands from the board computer and will turn back information with the state and values of the following parameters:

- Motor and/or line current;
- Input voltage;
- Faults and the type of the fault;
  - IGBT fault;
  - over temperature;
  - over current;
  - over voltage ($\geq$720Vcc);
  - low voltage ($\leq$ 420Vcc);
- allows functioning with damaged board computer with reduced speed and without electrical braking;
- Anti-slipping and anti-blocking software mechanism without information from rotation transducer (mandatory requirement).

b. **Functional requirements for** power supply source for auxiliary services

The static converter will ensure:
- Charging or accumulators (I_{max} = 40 Acc);
- Power supply for continuous current consumers.(max. 150 Acc);
- Power supply for alternative current consumers. (3x400V, maxim 4 KVA).

While the converter is running following signals are traced:
- Line voltage;
- Voltage and current in the intermediary circuit;
- Output continuous voltage(28Vcc);
- Loading battery current;
- Maximum voltage for battery loading;
- Three-phase output voltage;
- Output alternative voltage balance;

TENDER BOOK

MODERNIZATION OF THE ELECTRIC DRIVING SYSTEM FOR TRAMWAYS

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TENDER BOOK

MODERNIZATION OF THE ELECTRIC DRIVING SYSTEM FOR TRAMWAYS

1. THE OBJECT OF THE ACQUISITION

The Regia Autonoma de Transport Craiova (RAT Craiova) intends to modernize 9 tramways (6 of KT4D type, 3 of GT type) by replacing the present loading systems of the engines, respectively the auxiliary services with static converters.
The present Auction is deployed inside the MODERN Project, European Program FP7-CIVITAS Plus.
The full title of the project is: MObility, Development and Energy use ReductioN**.**
The purpose of the MODERN project is to increase, in its entirety, the level of life in towns by reducing the pollution due to public transport, by implementing some measures for reducing the energy use, by protecting the environment and for promoting a life style that should not depend by car transport.
The project highlights a package of integrated measures in all towns of the consortium, having a wide area of coverage for the requested thematic areas for the CIVITAS PLUS program.
The measures of the project and this tender book emphasize a good balance between the large scale applications based on existent and commercial technologies like the traffic management, info mobility and the optimizing of the energy use.

2. GENERAL SPECIFICATIONS

2.1 Generalities

Both tramways of KT4D type and of GT type found in use at RAT Craiova are appropriate from the constructive point of view, but the new requirements imposed by the European legislation determined by the gradual improvement of the public transport vehicles, the main objective being the loss reduction, that is the energy use optimization. The present structure of the drive systems of the two tramway types lead to great energy loss in all working modes: start (starting up), speed adjustment, braking. Also, a very important problem is connected to the high maintenance costs due to electro mechanic commutation elements. At present, the starting up, speed adjusting and electric braking are accomplished by successive short circuits of the serial resistance with the electric engine, energy recovery not being able in any of the cases.

2.2 The object and the application domain

Tramways of KT4D type are equipped with 4 (four) traction engines of 300 Vcc, 2 (two in series on the bogie) and, tramways of GT6 type with 2 (two) engines of 600 Vcc, one on each bogie. Both types can work on the continuous current network of 600Vcc (+20%; -30%), by connecting in series in the rotor circuitry of some corresponding resistance. This solution determines a low energetic efficiency.
The tramway modernization action includes major changes at the properly called traction

part. These changes regard the replacement of the controller of the classic drive with choppers realized with IGBT components, choppers that assure current control in all working regimes, the elimination of the contact makers that determine the running regime and braking regime of tramways and the input of auxiliary services through static converters.
A second objective of the tramway modernization is the replacement of the classic auxiliary services source with a static source that would feed all the auxiliary consumers, working in connection with the accumulator batteries, batteries that will be charged in a controlled voltage and current intensity regime.
Both the modification of the drive and of the auxiliary services source contribute to the substantial reduction and the maintenance times, by replacing some used equipments (contain a lot of moving mechanical components), with electronic equipments, a lot more efficient.

2.3 The accomplishment of modernization

The equipment bidder is obliged to:

- Modernize the tramways with its own qualified personnel for such type of works, in the R.A.T. Craiova workshops.
- To put at the disposal of the beneficiary the project of the force installation once with the submitting of the offer in order to be approved by the beneficiary with the solution of gaining electric energy, the presentation and the argumentation of the percentage of electric energy reduction.
- To prove the fulfilment of the technical conditions imposed by the present tender book and by presenting (physically/ on electronic support/ with photographs, folders and the results of the laboratory or tramway testing) of an equipment identical with the one bided (chopper with IGBT) once the bid is submitted.
- To deliver the equipments, electric fans with asynchronous engines with the rotor in short-circuit, force and command cables, electric schemes, cable journals, the project arrangement of the drive installations.
- To assure the technical assistance for the entire period of the modernization works, including their assembly.
- To bring the tramway into service.
- To train the operation and maintenance personnel.
- To prove the organization and the necessary endowment for the maintenance works and intervention in case of fault.
- To present recommendations from the beneficiaries regarding the object of the contract.

2.4 Reference documents

The functional and constructive characteristics of the equipments will be according to the following standards and reference norms:

a. Romanian standards

- STAS 10954-77: Rectifier with semiconductors. The general technical quality conditions.
- STAS 6692-83: Climatic protection. Types of climatic protection. (Categories of exploitation).
- STAS 6705-90: Metallic coverage. Electrochemical coverage of nickel and chrome. Quality technical conditions.
- STAS 7222-90: Metallic coverage. Electrochemical coverage of zinc or cadmium. Quality technical conditions.

- SR 10543-93: Electrochemical coverage. Electrochemical coverage with tin.
- SR EN ISO 2819:1996: Metallic coverage on metallic support. Electrochemical and chemical coverage. The list of the adherence verification methods.
- STAS 6854-90: Metallic coverage. The determination of the thickness of the layer using the drops method.
- STAS 8009-80: The protection of the metallic surfaces. Coverage through painting. Verification methods.
- SR EN 60068-2-1+A1+A2:1996: Environment testing. Testing A: Cold.
- SR EN 60068-2-2+A1+A2:1996: Environment testing. Testing B: Dry hot.
- STAS 6048/7-80: Radio electric perturbation. Equipments, machines and electric installations. Approved limits of the perturbation and special testing conditions.
- STAS 10191-85: The efficiency of the electronic components. Guide for the introduction of the efficiency regulations in standards and technical norms.
- STAS 12007/1; 5; 7-86: Efficiency testing of the equipments.
- STAS 10911-77: Efficiency, maintenance and availability. Gathering data regarding the behaviour in exploitation of the industrial products.
- STAS 10307-75: The efficiency of the industrial products; efficiency indicators.

b. International standards specific to the means of public transport endowed with electric drives

- CEI 571: Electronic equipments for the railway electric traction.
- CEI 411-1: Power traction converters.
- CEI 77: Applicable rules for the electric traction machines.
- CEI 349: Applicable rules for the electric rotary machines for railway and road vehicles.
- CEI 165: Rules for the testing of motor vehicles with electric traction, after mounting and before the putting into service.
- CEI 1133: Electric traction. Rolling. Methods for testing the vehicles.
- CEI 146: Converters with semiconductors.
- SR EN 50121-3-1:2003. Electromagnetic compatibility; Part 3-1: Rolling –Trains and complete vehicles.
- SR EN 50121-3-2:2003: Electromagnetic compatibility; Part 3-2: Rolling - Equipments.
- SR EN 50124-1:2002: Insulation coordination; Part 1: Fundamental regulations – Insulation distances through air and insulation distances on surfaces for all the electric and electronic equipments.
- SR EN 50124-2:2002: Insulation coordination; Part 2: Excessive voltages and associated protections.
- SR EN 50125-1:2003: Environment conditions for equipments; Part 1: Equipment of the rolling.
- SR EN 50125-2:2003: Environment conditions for equipments; Part 2: Fixed electric installations.
- SR EN 50125-3:2003: Environment conditions for equipments; Part 3: Equipment for the signaling and telecommunications.
- SR EN 50126:2003: Specification and demonstration of the efficiency, availability, maintenance and security (FDMS).
- SR EN 50153:2003: Rolling. Protection measures connected to the electric risks.
- SR EN 50155:2002: Electronic equipments used on rolling.
- SR EN 50163:2003: Input voltages of the electric traction networks.
- SR EN 50207:2003: Electronic power converters for rolling.
- SR EN 61373:2002: Equipment for rolling. Testing to shocks and vibrations.

- SR EN 60529 (CEI 529): Protection degrees assured through carcasses (IP Code).

c. Legislation

- LAW 406/2004 regarding the approval OG 62/2004 for the modification and the completion of the LAW 608/2001 regarding the evaluation of the conformity of products.
- LAW 240/2004 regarding the producer's responsibility for the damages generated by fault products.
- HG 891/2004 Supervision measures for the products' market.
- HG 119/ 2004 Settling the conditions for the introduction on the market of industrial equipments.

2.5 Surrounding environment requirements

The tramway is destined to the exploitation in areas with temperate continental climate:

- Climate area: N, according to SR HD 478.2.1 S1/2002 "Classification of the environment conditions. Part 2: Environment conditions present in nature";
- Exploitation category: 2, according to STAS 6692-83;
- Surrounding temperature: -33°C ÷ +45°C;
- Maximum relative humidity: 80% to 20°C;
- Maximum altitude during the use time: 1000m;
- Exterior agents: dust, rain, mud, snow, ice, fog, UV
- Atmospheric aggressiveness: heavy.

2.6 Mechanical conditions

Shocks and vibrations: according to the European norms for rolling (CEI 571).
Noise level: max. 80dB in exterior.

2.7 Electric conditions

Network voltage: 600Vcc (+20%; -30%).
The command circuits are feeded from the accumulator battery (24Vcc), that is found in tampon with the auxiliary services.

2.8 Conformity with the standard documents

The tramway corresponds to the IEC provisions regarding the construction and the function of the electric traction vehicles (noise, vibrations, environment requirements, insulation degree, radio parasites and constructive dimensions).

3. EQUIPMENTS' COMPONENT

The mentioned modernization supposes the realization and the assembling on each tramway of 2 types of static converters:

- Chopper for the input of the drive engine;
- Source for auxiliary services.
- Air-conditioning for the watt man cabin

3.1 Chopper

3.1.1 Technical characteristics

- commutation elements: IGBTs;
- input voltage: 600Vcc;
- input voltage variation: -30% ÷ +20%;
- chopper can function at the voltage of 800 Vcc and nominal current for 5 minutes according to EN 50163;
- chopper must be self protective if a short- circuit appears on the line when it functions as running or braking at the nominal current and nominal voltage; this testing will be mandatory at the putting into service;
- nominal output current for each engine: 180Acc;
- maximum start current for each engine: 380Acc;
- maximum braking current for each engine: 400Acc;
- flux reducing degree: maximum 65%;
- cooling through forced air ventilation;
- choppers' working frequency: 2000Hz

Connected in the electric tramway scheme, the equipment must assure the traction engines input according to the start, running and electric braking regime. In any of the regimes, the corresponding scheme for each regime must be made and the current in the engines must be controlled according to the commands given by the watt man.
For the electric braking regime the equipment must decide if the braking is recuperative or rheostat, and the voltage at the generator's terminals should not overpass the maximum admitted value of 750 Vcc (can be set).
The chopper must eliminate all the electro mechanic commutation elements that determine the running-braking regimes – mandatory condition.
The chopper's commanding unit, the transducer's current and the voltage as well as the afferent input sources will be located inside the chopper's carcass.
The commanding unit will take through CANopen communication the commands from the board computer and will transmit information regarding the state and the values of the parameters (mandatory requirement):

- current through engines and/or line;
- input voltage;
- damage state and its type:
  - IGBT fault;
  - Over temperature;
  - Overcurrent;
  - Over voltage;
  - Minimum voltage;
- will allow the tramway's function with the fault board computer, with reduced speed and without electric braking (mandatory requirement);
- will assure in a mandatory way, anti skidding and the anti blocking of the engines' bogies without using the information from further transducers' rotative speed; this requirement will be fulfilled through a software implemented in the command unit.

3.1.2 Board computer

The board computer will be located in the watt man's cabin where air-conditioning will be assured.

The choppers and the source for the input of the auxiliary services will be monitored and controlled by the board computer whose software dedicated to the tramway will be made according to the safety norm for the circulation of the electric traction public transport EN 50128.

The board computer will mandatory fulfill the following minimal functions:

- will command the choppers' function in all function regimes:
  1. running in normal function conditions;
  2. braking in normal function conditions;
  3. running in fault regime with a traction circuit of a fault bogie;
  4. braking in fault regime with a traction circuit of a fault bogie;
  5. emergency braking actuated by passengers or by the watt man or in the case of the lack of the watt man; this supposes the drive of all tramway's braking systems.

the realization of the "washing" regime that supposes the tramway's function through the washing installation with reduced voltage (48 Vcc).

- will transmit to the choppers the imposed value of the current through the traction engines, proportional to the acceleration or braking pedals' actuation degree, respectively to the controller;
- will command the disc crosshead shoes and braking;
- will command and monitor the contact makers from the force circuit in normal and fault regime;
- will immediately command after the stopping of the tramway's input when major faults occur in the traction installation and in other installations;
- will control the flux wakening of the traction engines, without excitation current snaps and rotor up to the value imposed by the beneficiary;
- diagnosis through data storage in the memory of the unit and with the possibility of inspection with a specialized software; supplementary, the diagnosis software must be used unconditionally, temporarily and independently from the periodic data storage that would allow short times and the inspection of the state of the equipments at a certain moment; the taking over of the events in the function of the tramway will be made through communication RS 422/485;
- will monitor the function of the static source;
- will post on a graphic display of minimum 320X240 pixels the following information:
  1. date and hour;
  2. speed in km/hour;
  3. consumed /recovered energy – instantaneous value, average value;
  4. distance covered;
  5. fault regime and type of fault**.**

The board computer will be endowed with a radio module with operation in 433 MHz, the module that will allow the wireless command, remotely, during running, of the semaphore automata, for assuring the function "green light". In this context, the bidder will assure the technical support and the necessary services for undertaking this function.

3.2 Source for the input of the auxiliary services (static converter)

The static converter will assure:

- the charging of the accumulator batteries with I_{max} = 40 Acc, can be set;
- the input of the c.c. consumers with Imax.= 150 Acc;

- the input of the c.c. consumers with 3x400V/ 1,5 KVA for the tri-phase asynchronous engine fan for the chopper cooling.
- the input of the equipment for the air condition in the watt man's cabin with 220V/50Hz/1,5KW.

During the function of the converter the following signals are being watched:
- Line voltage;
- Voltage and current in the intermediary circuit;
- Output voltage in continuous current (27Vcc);
- Charge current of the accumulator battery;
- Load current of the cc consumers;
- Maximum charge voltage of the accumulator battery;
- Tri-phase output voltage;
- Symmetry of the voltage on output in alternative current;
- Current at the ca output;

The adjustments for the continuous current outputs and alternative current are independent, so that the input in limitation of one should not affect the other.

Technical characteristics :
- nominal input voltage: 600Vcc;
- variation domain of input voltage: -30%…+20% from 600Vcc;
- tri-phase output voltage: 3x400V / 50Hz;
- mono-phase voltage: 220V/50Hz made from the realization of the battery voltage of 24 Vcc,
- variation domain of mono-phase and tri-phase voltage: maximum +/- 10%;
- variation domain of frequency to nominal frequency: +/- 1%;
- asymmetry of charge between phases: maximum 30%;
- continuous nominal voltage to output: 28Vcc;
- adjustment domain of continuous voltage: 24…30Vcc;
- adjustment domain of battery charge current: 15…40Acc;
- nominal output current 190A;
- stationary deviation of the continuous output voltage, under the conditions of maximum admitted variation of input voltage and of the output current between 10% and 100% from I nominal output: +/-2%;
- continuous voltage wave at output: maximum 1,2Vcc;
- over load capacity: 1,5 from Inom time of 5 min;
- protection degree IP 64;
- cooling: natural convection.

Source protection:
- external short-circuit both on the c.c. output and on the c.a. output;
- internal short-circuit;
- over temperature;
- overload;
- charge with inverse polarity;
- lack of phase on the c.a output.

<u>In case of activating any above mentioned protection, the board computer will receive the information through the CANopen communication for displaying it (mandatory requirement)</u>

3.3 Air-conditioning for the watt man cabin

- To assure an interior temperature inside the cabin of 20ºC at an exterior temperature of 45ºC;
- The volume of the cabin: 3,5m^3.
- The possibility of setting the temperature in the range of 17 - 27ºC;
- Input from the auxiliary services source.

4. IMPOSED CONSTRUCTIVE CONDITIONS

The electronic equipment will be placed in the available spaces on the tramway, without important modifications of the coachwork.
The connection in the electric force scheme will require modifications and works of minimum constructions / assembling.
One will assure the electric insulation between force and command. The contact makers that remain in the scheme will be the ones existent on the tramway.
The products assure the security of the electronic low voltage equipment users, and the producers must respect the laws regarding the evaluation of the conformity of products.
The equipments must have assured the following protection coverage:

- electrochemical protection coverage (according to STAS 10543/1993 and STAS 7222-90 for hard exploitation conditions) for the assembling organs and the connection bars;
- paint protection coverage (according to STAS 8009-80, minimum paint thickness 80μm and the degree of detachment of the paint layer 2), for the source carcasses;
- eloxation protection coverage (according to STAS 7043/1-93, minimum thickness 15μm), for the radiators of the electronic power components.
- coverage of the threaded marks will be accordingly, for hard exploitation conditions;
- insulation materials are resistant to hardness testing, excessive heat and fire (CEI 947-1/1992). Cables are being used with insulation raylon (up to the 4mm section) and resistant cables to fire and that do not release toxic gas and no compounds halogenated (section larger than 4mm).

5. TECHNICAL QUALITY CONDITIONS AND THE RECEPTION CRITERIA

The equipments will entirely respect the legal provisions and the specific normative documents in use, in a contrary case these will be not considered true.
Mandatory, the equipment producer will be certified by a competent institution regarding the management of the quality assurance in conformity with SR EN ISO 9001 / 2001 and SR EN ISO 14001/2005.

5.1 Insulation resistance

The measurement of the insulation resistance is being made according to the EN 50 207 with the megger at a voltage corresponding to the nominal voltage of the verified circuit (1000 Vcc, respectively 500 Vcc), in the following way:

- between the 600Vcc short-circuited terminals and the other short-circuited terminals and connected to the carcass with the testing voltage of 1000Vcc, R > 5 MOhms;
- between the terminals with a potential of 24 Vcc and its own carcass that the other short-circuited terminals are connected to with the testing voltage of 500 Vcc, R > 1 MOhms;

5.2 Dielectric testing

The dielectric testing will be made according to EN 50 124-1 in the category of over voltage OV 3 and the pollution degree PD 3. The testing voltage is alternative with the frequency of 50 Hz and must be obtained in 5 seconds and maintained for a minimum period of 10 seconds.

- the value of the testing voltage of the insulation between terminals with 600Vcc potential and the other short-circuited terminals and put at the carcass is 2,8 kV for chopper and the auxiliary services source.
- the value of the testing voltage of the insulation between terminals with 24 V and the other short-circuited terminals and put at the carcass is 0,42 kV for chopper and the auxiliary services source.

If the testing must be repeated, the testing voltage must be reduced with 20%.

5.3 Function at over voltages of the input network

The equipment functions normally if over voltages appear in the input network according to CEI 411-4/1996, pct.10.3.3.

5.4 Function at step change of the line voltage

The equipment functions normally, in the specified parameters, when the input voltage varies in snaps of 20% from the maximum value of the voltage, applied in the function of the equipment at nominal input voltage.

5.5 Conditions regarding the vibrations

The product must resist at vibration and shock testing according to EN 61373:1999 (category 1, class B), in the following conditions and order:

a. simulation of the vibration conditions from exploitation

- Frequency range: 5 ... 150Hz;
- Acceleration: vertically: 7,9 m/s^2;
  transversal:3,5 m/s^2;
  longitudinal: 5,5 m/s^2;
- Testing time: 5 hours on each of the three axes reciprocal perpendicular.

b. shock testing

- Maximum acceleration: 30m/s^2;
- Duration: 30ms;
- Number of shocks applied: three shocks on each of the three axes reciprocal perpendicular both in a positive direction and in a negative direction (total of 18 shocks: 3×3×2).

c. random vibration testing

- Frequency range: 5 ... 150Hz;
- Acceleration: vertically: 1 m/s^2;
  transversal: 0,45 m/s^2;
  longitudinal: 0,7 m/s^2.

The products must resist to shakings that may appear during transport, according to STAS

8393/18-90:

- number of shakings: 400 ± 10 shakings;
- frequency: 100 shakings/min at 10g.

5.6 Acoustic noise

The converter, in a function state at nominal burden, issues an acoustic noise lower or at most equal to $65dB_A$ at a distance of 1,5m (acoustic noise class N1, according to EN 50207:2003).

5.7 Heating

The equipments will function at nominal input and charge parameters, without the temperature on subassemblies to exceed the following maximum values for a surrounding temperature of 40 ° C:

- the radiators of the electronic power components: +70° C;
- filter condenser: +70° C;
- inductives, transformers: +100° C;
  - connection bars: +70° C.

5.7 Behavior conditions at excessive heat, fire and material hardness

The parts from the electric insulation materials must resist to hardness testing at the temperature of 150° C. The fire resistance is made at the temperature of 950°C for the pillars of the parts under voltage and at 650°C for the other parts (cf. CEI 947/1-96 and SR EN 69695-2-1/1-98).

5.8 Behavior to short-circuit

The converter is internally protected, with the sensing electronic circuits, at the external short-circuits, both on the alternative current part and on the continuous current part.

5.9 Efficiency indicators

It is appreciated that the average estimated time for a good function is of 15.000 hours in a normal exploitation regime.
The level of estimated trust p = 0,9.
Maximum repair time: 3 hours

5.10 Rules for the quality verification

Comprises the technical verification conditions mentioned previously:

- Insulation resistance
- Dielectric testing
- Function at over voltages of the input network
- Function at the step change of the line voltage
- Heating
- Behaviour conditions at excessive heat, fire and material hardness
- Behavior to short-circuit

The bidder will present, with the occasion of the offer, a Report of the product quality verification meeting, on a neutral stand, signed by the RAT Craiova representatives, present at these verifications.

5.11 Marking, packaging, storage

For each equipment and for each subassembly there is an indication label with the following content:

- the emblem of the producer;
- fabrication year;
- number or batch;
- type of equipment;
- important characteristics (input voltage, output voltage, mass, output power, etc.).

The products will be assembled, considering the distance or the means of transport, in wooden cases, plastic material or polythene foil.

The storage of the product on the long run must be made in closed locations in which the following environment conditions must be met:

- surrounding temperature: -35°C ÷ +40°C;
- relative humidity: 50 ... 80% la 25°C;
- no dust, metallic powder, corrosive agents.

It is forbidden the equipment overlying.

6. TECHNICAL TRAMWAYS CHARACTERISTICS

6.1 Tramways of KT4D type

6.1.1 General data

- number of axles: 4 (BO+BO);
- number of places: 34;
- total number of places: 122;
- own wight: 19.500 kg;
- total weight: 31.200 kg.

6.1.2 General dimensions

- length of the coupling vehicle: 10.054 mm;
- length of the vehicle: 2.180 mm;
- height of the vehicle: 3.400 mm.

6.1.3 Electric installation

- number of engines: 4;
- working voltage: 600 Vcc;
- low voltage: 24 Vcc.

6.1.4 Working parameters

- maximum speed: 50 km/h;

- maximum acceleration: 1,4 m/s^2;
- maximum negative acceleration: 1,6 m/s^2;
- maximum start current: 380 A;
- maximum current for electric braking: 400 A.

6.1.5 Electric engines

The traction engines are of continuous current with series excitation.
The cooling of the engines is made with the help of a ventilation installation.
The traction engines have the following technical characteristics:

- P_N = 40 KW;
- n_N = 1.460 rpm;
- U_N = 300 Vcc;
- $I_{nominal}$ = 150 A.

6.2 Tramways of GT6 type

6.2.1 General data

- number of axles: 6 (BO'-B-BO');
- number of places: 40;
- total number of places: 180;
- own wight: 35.000 kg.

6.2.2 Electric installation

- number of engines: 2;
- working voltage: 600 Vcc;
- low voltage: 24 Vcc.

6.2.3 Working parameters

- nominal current: 180 A.

6.2.4 Electric engines

The traction engines are of continuous current with series excitation. Natural ventilation.
The traction engines have the following technical characteristics:

- P_N = 150 KW;
- n_N = 1.350 rpm;
- U_N = 600 Vcc;
- I_N = 280 A.

The engines are of WD785 type.

7. DELIVERY, RECEPTION

The final price must include all the expenses, including the training of the operation and maintenance personnel.

The delivery, assembly and the putting into service terms will be clearly stipulated in the contract and will be appropriate to the following diagram:

Curr. No.	Tramway No.	Tramway type	Period for receiving the chopper
1	105	KT4D	31.12.2009
2	101	KT4D	31.12.2009
3	102	KT4D	28.02.2010
4	104	KT4D	28.02.2010
5	109	KT4D	30.04.2010
6	110	KT4D	30.04.2010
7	651	GT6	31.12.2009
8	653	GT6	28.02.2010
9	660	GT6	30.04.2010

8. WARRANTY CONDITIONS AND THE PRODUCT WARRANTY

The warranty period for the products is of minimum 24 months, starting with the moment of its reception.

The honoring of the warranty cannot be conditioned by the fulfillment of some special conditions, other than the ones mentioned in the offer and accepted by the buyer, no matter their nature, be that technical, function conditions or exploitation personnel.

The operations that are under warranty must be assured in such a way that the buyer should not pay transport costs, demounting, installation, reconfiguration or other costs.

The intervention time during the warranty period is of 24 hours from the moment of acknowledging the fault, by the beneficiary.

9. DOCUMENTS THAT WILL ACCOMPANY THE PRODUCTS

- Technical documentation necessary for the use (technical book) and maintenance (service manual).
- Card with the lot testing.
- Invoice.
- Warranty and conformity certificates.

The service manual comprises:

- functional technical and overall size characteristics;
- electronic schemes of the component plates and the location drawings from which one should see the name and their values;
- the description of the overall function, on subassemblies at the plate electronic level;
- the verification instructions of the blocks and of the electronic plates by making evident the input voltages and of the measure points;
- the hypothetical flaws description and of the remedy ways;
- the diagnosis software and the control on electronic support, with use instructions;
- assembly instructions for force components;
- putting into service and exploitation instructions;
- maintenance instructions;
- the list of exchange parts that should comprise the catalogue codes of the suppliers for all equipment components;

- the list of necessary verification equipment for the service process;
- measures for work protection.

Once with the reception of the delivered products there will also be made the reception of the complete service documentation, the service manual, and general electric scheme and of the location drawing of the component elements, of the “as-built” documentation.

Adjustments for continuous and alternative current outputs are independent so that if one enters in limitation the other one is not affected.

c. **Functional requirements for board computer**

The board computer will be placed in tram-driver's cabin which is ensures the right climate.
The choppers and the power supply source for auxiliary services will be supervised and controlled by the board computer which has dedicated software according to EN50128 standard for electrical drive transport.
The board computer will have the following minimal functions:

- Will command the chopper in all functional regimes:
    1. Running in normal conditions
    2. Braking in normal conditions
    3. Running in case of fault to one of the truck electrical drive circuit
    4. Braking in case of fault to one of the truck electrical drive circuit
    5. Braking in case of missing tram-driver;

- Will transmit to the choppers the established value for motor current proportional with the degree of mechanical drive of the acceleration/braking pedals or controller;
- Will command the pattens and disk brakes;
- Will supervise and command the contactors from the power circuit in normal functioning and fault regimes;
- Will command the immediate stop of the tram's power supply in case of major faults in any electrical installation;
- Will command continuously flux attenuation for the motors without any significant jumps for exciting and rotor currents till the value prescribed by the beneficiary;
- Diagnosis by data storage and the possibility to inspect data by the meaning of a dedicated software; additionally the software permits to be used unconditionally, temporary and independent for periodic data storage to allow quick diagnosis and inspection; to download data RS422/485 communication is used;
- Will supervise the static power supply;
- Will display on a minimum 320x240 screen the following information:
    1. Date and time;
    2. Speed(km/h);
    3. Energy consumption- instantaneous and medium values;
    4. Covered distance(km);
    5. Fault regime and the type of the fault;